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Nutrient fate after the coagulation–flocculation process of fish-farm water using green coagulant

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ABSTRACT

The aquaculture industry requires to change the water of fish aquarium every day to maintain high production quality. In this study, we assessed the use of the coagulation–flocculation process to treat fish-farm water with green coagulant concentrations (100, 300, and 500 mg/L) to remove turbidity, total suspended solid (TSS), and total dissolved solid (TDS). Phosphate (PO_4) and nitrate (NO_3) throughout the treatment were detected in fish-farm water, and Fourier transform infrared (FTIR) analyses were conducted for green coagulant and flocs. Jar tests revealed that the coagulants were able to reduce turbidity – 87%, TSS – 72.72%, and TDS – 8.33% and turbidity – 90%, TSS – 86.36%, and TDS – 9.16% by palm pith and watermelon rinds respectively at a dosage of 100 mg/L. Through FTIR analyses, cellulosic materials were found in green coagulant which contributed to the efficacy of the coagulant. Additionally, phosphate increased in water owing to its release from palm pith and watermelon rinds, as confirmed by FTIR results. This study concluded that recovered nutrients and treated water contributed to the enhancement in plant growth as fertiliser and irrigation water.

Keywords: aquaculture, cellulosic materials, flocs; green coagulant, nutrients.

INTRODUCTION

Potable water is only 2.5% of the total world water and is utilised in domestic, industries, aquaculture, and agricultural activities. This water returns to the environment as wastewater; sustainable goals such as recovery, recycling, and reuse are needed (Al-Baldawi et al., 2022). The aquaculture industry is a major and common industry utilising large quantities of clean water. Aquaculture-industry wastewater contains rich nutrients, such as organic, ammonia, nitrates, and phosphates (Nathanailides et al., 2023). Many methods are used to treat aquaculture effluent, including physical (filtration and sedimentation) (Karia et al., 2022), chemical (coagulation–flocculation and precipitation) (Ma et al., 2024), and biological treatments (bioreactor and bioremediation) (Imron et al., 2024; Pramanik et al., 2024; Mutar et al., 2022). Coagulation-flocculation is a simple and important process in water-treatment plants to achieve high turbidity removal (Hussain & Al-Baldawi, 2025). Turbidity is an important drinking-water parameter because it reduces water transparency and can serve as a medium of contaminants and microorganisms (Fadhil et al., 2019). Turbidity is caused by colloidal particles with sizes between 1 nm and 1 μm which can be removed by free settling or filtration (Dandesa et al., 2023). Additionally, the particles have a negative electrical charge on the surface, leading to the development of an opposite force amongst similar particles. Thus, for destabilised colloidal particles, special conditions as high and low mixing speed and settling time are needed to aggregate particles into larger flocs (Salem et al., 2023). Coagulants are predominantly chemical based, so an alternative option is plant-based coagulants which are safe, environmentally friendly, and sustainable (Salem et al., 2024). Coagulants are positively charged, and under rapid mixing, neutralisation achieved with the negative charges on the colloids to achieve the electric destabilisation of the suspended particles (El Mouhri et al., 2024).

Through rapid mixing, the coagulant and particles bind and form flocs. Subsequent low mixing can allow floc aggregation and increased size. At the final stage of the process, the flocs settle to the bottom and clear water forms above. Several factors play roles in coagulation–flocculation, such as coagulant concentration, pH of treated media, fast and low speed of the mixing, and settling time (Jathan & Marchand, 2024). Different parameters such as pH and coagulant concentration can influence the efficiency of the coagulation–flocculation treatment (Hartal et al., 2024). Interest in using natural coagulant in wastewater treatment is growing because of concerns regarding the environmental effects of inorganic coagulants. A challenge that must be addressed for plant-based coagulant is plant selection and the evaluation of the compounds that represent the plant-based coagulant and influence water quality owing to release some ions which need to search on it. In this study sustainability natural coagulant of palm pith and watermelon rinds were investigated as friendly to environment and cost-effective alternative to inorganic coagulants. The aim of using natural coagulants is to treat fish-farm water for the purification of water and the recovery of flocs rich in nutrient as fertiliser. Moreover, the study is concentrated on the fate of nutrients (phosphate and nitrate) in fish-farm water after treatment by green coagulant.

MATERIALS AND METHODS

Water sample source

The wastewater used in this study was from a fish-farm industry in Baghdad city (Figure 1). The farm has four basins with a capacity of 10 m^3 water. Table 1 shows the characteristics of the collected fish-farm water.

Coagulant preparation

Two natural coagulants were selected of palm pith and watermelon rinds, collect, cuts, dried, and crush to get fine powder. The plant powder with deionised water was shook for 30 min, filtered with cloth, and passed through filter paper to use as a green coagulant (Muniz et al., 2020).

Green-coagulant experiment

The jar test at a laboratory scale was used with fish aquaculture water comprising a series of six jars (Lovibond, Germany). Fish-farm water (500 mL) was poured into a 1 L beaker. Green coagulant extract was added for the coagulation–flocculation process as water treatment. Jar test was run with two green coagulants palm pith and watermelon rinds, 5 min with 200 rpm speed mixing, slow mixing 30 rpm for 30 min. Finally, the treated water was left to settle for 30 min (Daud et al., 2023). The influence of the green coagulant concentration (100, 300, and 500 mg/L) on fish-farm effluent was studied to investigate best condition of turbidity and total suspended solid (TSS) removal, as well as the fate of nutrients

Table 1. Fish-farm industry parameters

Parameters	Unit	Value
pH		7
Turbidity	NTU	45
Total suspended solid	mg/L	22
Nitrate	mg/L	0
Phosphate	mg/L	0.51

Figure 1. Fish farm in Baghdad

(nitrate and phosphate). The removal efficiency was calculated using equation 1 (Hatim et al., 2024; Mutar et al., 2023):

$$\%Removal\ (Turbidity, TSS, TDS) = \\ = \frac{FF_{Ci} - FF_{Cf}}{FF_{Ci}} \times 100 \quad (1)$$

where: F_{Ci} is fish-farm water before treatment, and FF_{Cf} is fish-farm water after treatment.

Water-analysis methods

The water-quality parameters turbidity, TSS, total dissolved solid (TDS), nitrate, and phosphate of the raw and treated effluents were measured according to the APHA Standard Methods for the Examination of water and wastewater (APHA, 2017). The following instruments were used: for pH and TDS, a pH metre (FOCUS ON LAB, China); for turbidity and TSS, a turbidity metre (Lovibond, TurbiCheck, Germany); and for nitrate and phosphate, a HACH DR3900 spectrometer (Germany).

Fourier transform infrared (FTIR) characterisation of floc before and after treatment

The functional groups of the palm pith and watermelon rinds powder were analysed before and after the coagulation–flocculation process by using an FTIR spectrometer (IRA ffinity-1Shimadzu Scientific Instruments, Japan). Fish-farm sludge was analyzed for comparison. The target of the FTIR analyses was to determine the changes in the characterisation of surface morphology in the green-coagulant active components which played a significant role in the coagulation–flocculation process. The FTIR spectrum of fish-farm sludge and flocs generated after treatment was also presented in parallel with the spectrum of green-coagulant powder for easy comparison.

RESULTS AND DISCUSSION

Performance of green coagulant to treat real aquaculture industry

To evaluate the potential to purify fish-farm water effluent, a jar test was performed with various coagulant concentrations. The addition of palm pith and watermelon rinds showed a positive effect by decreasing the the turbidity and suspended and dissolved solids concentration compared with settling without coagulant addition. The best decrease tendency by palm pith and watermelon rinds coagulant were turbidity (5.85 NTU), TSS (6 mg/L), and TDS (1100 mg/L), whereas the values for watermelon rinds coagulant were turbidity (4.48 NTU), TSS (3 mg/L), and TDS (1090 mg/L) at 100 mg/L (Figure 2 and 3). For 300 mg/L coagulant concentration, palm pith and watermelon rinds showed almost the same results at 100 mg/L, whereas the result at 500 mg/L coagulant concentration was less than that at 100 and 300 mg/L. The removal efficiencies were (turbidity = 87) (TSS = 72.72) (TDS = 8.33%) and (turbidity = 90) (TSS = 86.36, TDS = 9.16) for 100 mg/L palm pith and watermelon rinds, respectively. Indeed, a higher dosage of green coagulant did not consistently produce better results. When the charge was oversaturated, the opposite forces amongst primary particles rise, leading to a reduction or inability in binding, causing the floc density to drop and resulting in particularly loose flocs (Xu et al., 2024). From this assessment, the palm pith and watermelon rinds dosage of 100 mg/L used in this study was deemed suitable for fish-farm water coagulation–flocculation process. Hussain and Al-Baldawi (2025) achieved 47% turbidity removal with 500 mg/L watermelon rinds. This value was less our finding, proving that 100 mg/L watermelon rinds were more efficient with 90% turbidity removal (Hussain & Al-Baldawi, 2025). Kouniba et al. (2024) also used watermelon rinds to treat water contaminated by metals and turbidity. They obtained 99.21% turbidity removal at 200 mg/L coagulant concentration. For palm pith, little research just previous study to treat turbid water and reached 48% turbidity removal with 500 mg/L (Hussain & Al-Baldawi, 2025).

FTIR spectral analysis before and after treatment

The functional groups in palm pith, watermelon rinds, and fish-farm sludge were evaluated using FTIRIR, and the spectra are presented in Figure 3 and 4 for palm pith and watermelon rinds, respectively. FTIR spectroscopy analysis revealed more than two peaks on the spectra for functional groups of N-H (3300–3500 cm^{-1}), O-H (3200–3600 cm^{-1}), and P-O (1100–1250 cm^{-1}). They corresponded with the coagulants that caused floc formation and consequent turbidity removal while phosphate increased (Addich et al., 2024; Benalia et al., 2024). The main

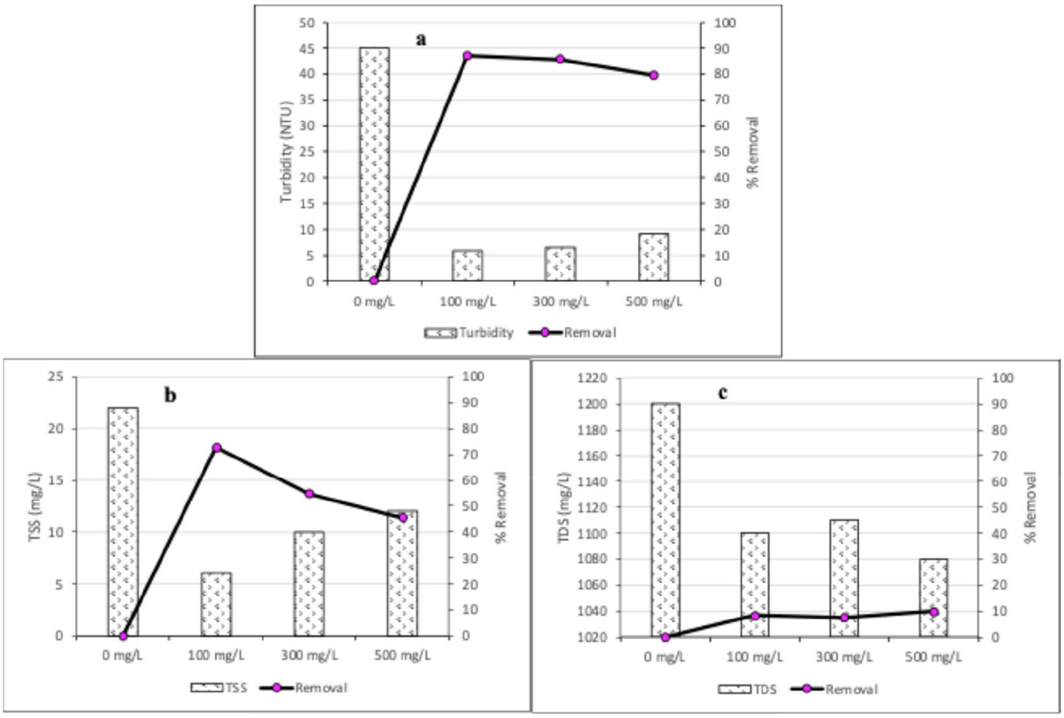

Figure 2. Effect of coagulant concentration on the removal of (a) turbidity, (b) TSS, and (c) TDS for palm pith from fish-farm water

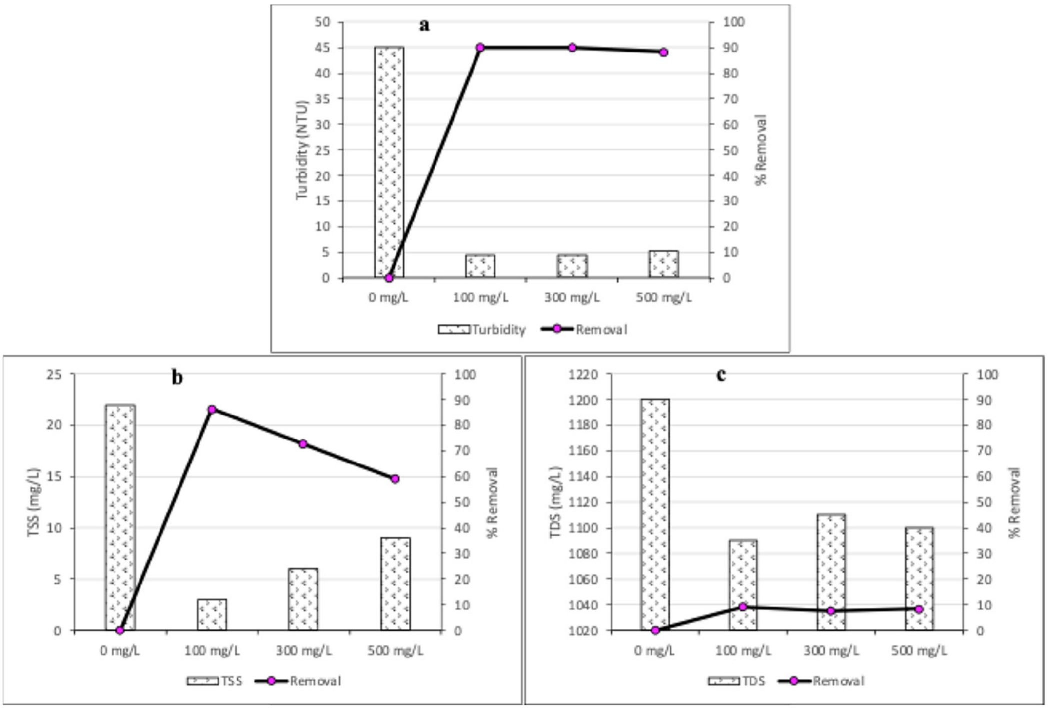

Figure 3. Effect of coagulant concentration on the removal of (a) turbidity, (b) TSS, and (c) TDS for watermelon rinds from fish-farm water

standard polysaccharide bands were assigned for palm pith and watermelon rinds powder in the bands at the 3336 and 3338 cm^{-1} region, which corresponded with O-H stretching vibrations. The O-H group belonged to carboxylic acids, phenols, and alcohols that were related to lignins and/or polysaccharide compounds. They played roles in the coagulation–flocculation process

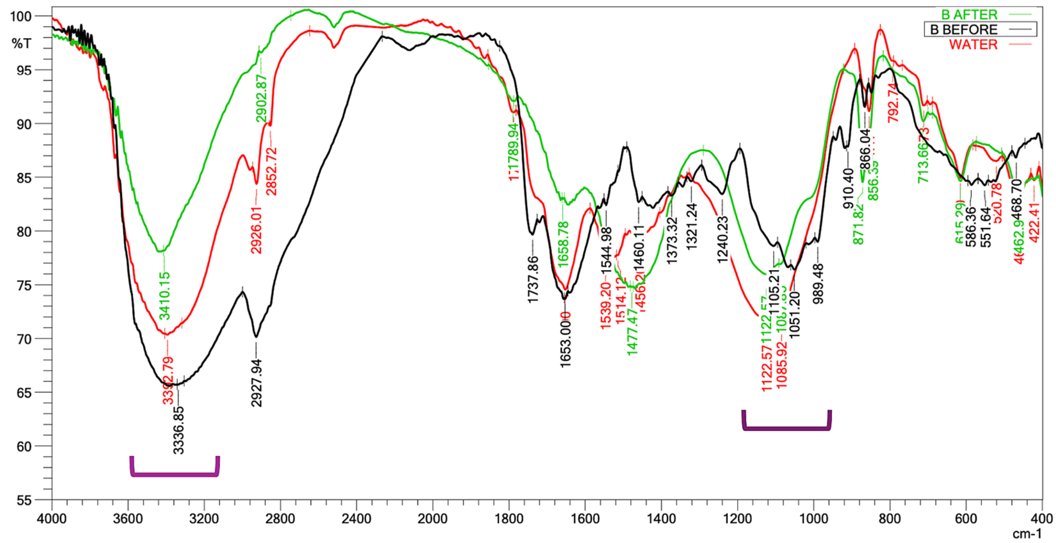

Figure 4. FTIR spectra of palm pith powder (black), fish-farm sludge (red), and flocs after treatment (green) with the main absorption bands

by providing adsorption sites for suspended and colloidal matter (El Gaayda et al., 2024; El Mouhri et al., 2024).

The polysaccharides compounds were found in the 900–600 cm^{-1} region, indicating that these compounds played roles in the coagulation–flocculation process. The spectra obtained from the C–H stretching (2800–3600 cm^{-1}) region can also be used to detect exposed starch as the hydroxyl radicals formed by the separation of water molecules that attacked the hydrogen of any C–H bonds and released the hydrogen atom from the bond. Furthermore, changes in the peaks within 1200–1000 cm^{-1} of the three spectra of fish-farm floc, green-coagulant powder, and fish-farm floc after green coagulant exposure, the changes in C–N stretch. These results showed that floc generation occurred when green coagulant was added due the bridging mechanism during flocculation when hydrogen bonds formed between the starch and the suspended particles, as mentioned by Asharuddin et al. (2023). Aquaculture effluent is rich in nutrients such as nitrogen and phosphate. Treatment with green coagulant can recover the nutrient content; thus, it can be used as a natural fertiliser in agriculture (Alnawajha et al., 2022).

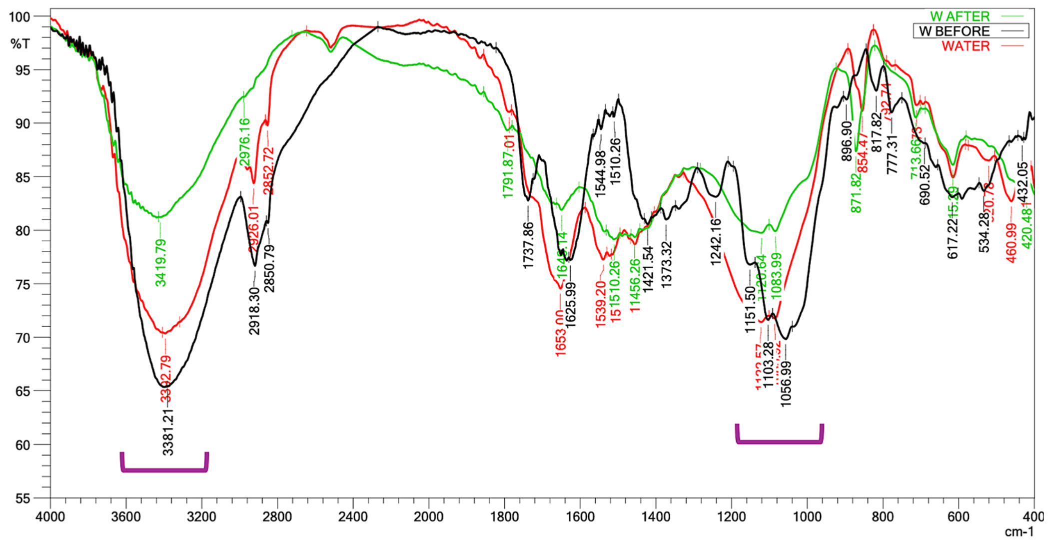

Figure 5. FTIR spectra of watermelon rinds powder (black), fish-farm sludge (red), and flocs after treatment (green) with the main absorption bands

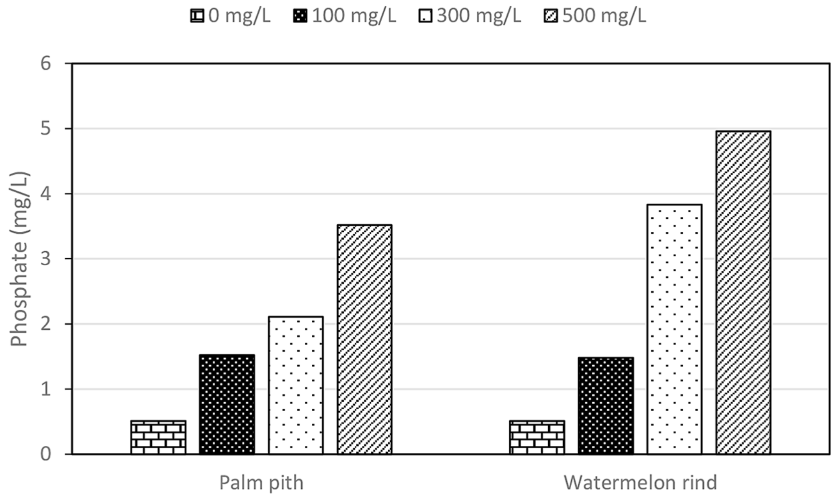

Figure 6. Phosphate concentration after treatment with palm pith and watermelon rinds

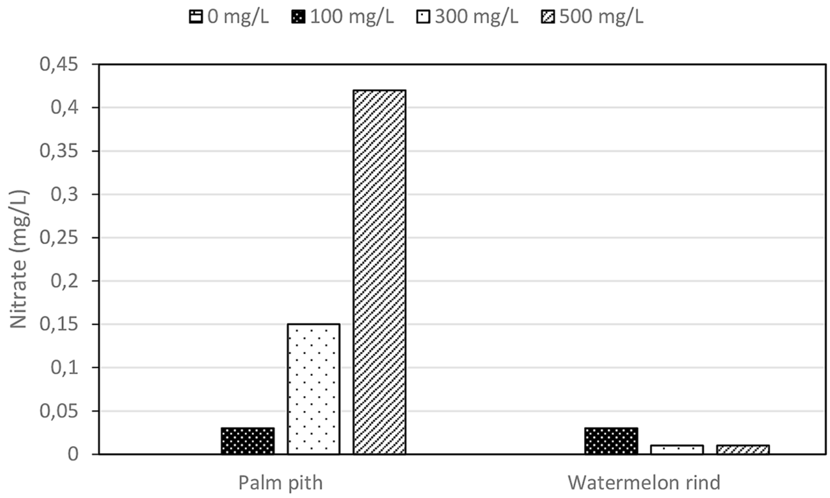

Figure 7. Nitrate concentration after treatment with palm pith and watermelon rinds

Phosphate and nitrate after treatment of fish-farm water

Phosphorus and nitrate are basic components of fertilisers and feed supplements for crop and livestock production (Martín-Hernández et al., 2023). The phosphate and nitrate in raw fish-farm water were low at 0.51 and 0 mg/L respectively. After coagulation–flocculation process, results showed the low ability of green coagulant to remove phosphate and nitrate from fish-farm water. Adding the natural coagulants palm pith and watermelon rinds for coagulation–flocculation process increased the PO_4 and NO_3 level, as shown in Figure 6 and 7. The U.S. Environmental Protection Agency sets 2 mg/L as the phosphate limit when discharged onto surface water to prevent environmental issues like eutrophication, which can harm aquatic ecosystems and degrade water quality. Our results showed that the phosphate concentration increased to 3.52 and 4.96 mg/L when the coagulants palm pith and watermelon rinds were used, respectively, with increased coagulant concentration from 100 mg/L to 500 mg/L. The FTIR spectra demonstrated that phosphate levels increased owing to the natural coagulants, indicating that they can be utilised to treat water and enhance plant growth by irrigating agricultural crops.

CONCLUSIONS

Two natural coagulants were tested at 100–500 mg/L to select the best concentration and detect nutrients after jar tests. Results showed that a low coagulant concentration yielded the best turbidity removal efficiency of 87% and 90% for palm pith and watermelon rinds, respectively. FTIR analysis of the palm pith and watermelon rinds powders revealed the presence of aliphatic amine (C-N) stretching, carbonyl (O-H), and alkyl (C–H) functional groups, which were characteristic of cellulosic materials and thus did not cause any secondary impact on treated water. Additionally, FTIR confirmed the reason of the increase in phosphate and nitrate from the N-H, O-H, and P-O groups, which were released from natural coagulants. The benefits of using palm pith and watermelon rinds as coagulants for water treatment were that they were biodegradable and can thus be used for drinking-water treatment instead of aluminium sulphate.

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